



METHODOLOGY NOTE

Loss attribution. How we calculate it.

Definitions, formulas, source-class assignment, and worked examples for the loss-attribution waterfall used in the LumeTrax Vision quarterly performance report and the LumeTrax Audit & Assurance bankability review.

DOCUMENT	Loss Attribution Methodology — v1
AUDIENCE	Asset managers · lender's IE · independent reviewers · technical operations leads
RESOLVES	Footnote references [L.2] through [L.8] in vision-sample-report-v1 and audit-sample-v1
VERSION DISCIPLINE	Pinned per engagement at engagement initiation. Changes between periods disclosed in the report's methodology section
RELATED	Architecture Brief · Vision sample · Audit & Assurance sample

This document is the methodological backing for every loss-attribution figure in a LumeTrax deliverable. When the lender's IE asks how a number was computed, this document answers — including assumptions, exclusions, and the conditions under which a judgement call was made instead of a calculation. Period-over-period comparability is a methodology property, not a coincidence.

Issued 2026-05-08 · Document version: loss-attribution-methodology-v1 · Aligned to IEC 61724-1 (PV system performance monitoring) and IEC 61400-26-1 (capacity-weighted availability).

1. What loss attribution is, and what it isn't

Loss attribution decomposes the gap between weather-normalized expected energy production and actual energy delivered into named loss buckets — soiling, shading, inverter clipping, curtailment, equipment downtime, weather variance, anomaly. Each loss bucket is auditable to the underlying historian record, alarm event, or operational entry that generated it.

The decision the report enables: which losses are recoverable through O&M; action, which are claimable from a counterparty, which are physics. The first two get tickets in Asset Manager and counterparty-allocation entries on lender / insurer reports. The third gets accepted, recorded, and excluded from recovery expectations.

What loss attribution is NOT

- It is not a forecast. Loss attribution is a backward-looking decomposition of a period that has already happened.
- It is not a P&L; It is an energy decomposition (in MWh) that the customer's commercial team translates into a P&L; using their tariff and contract structure.
- It is not an OEM-warranty trigger by itself. A loss bucket assigned to OEM warranty is evidence; the warranty claim follows the contract's claim process.
- It is not a single number. The output is always a waterfall (Expected → losses by bucket → Actual), not a headline % deviation.

The standard waterfall structure

Every LumeTrax loss-attribution waterfall has the same 9-row structure (rows added/removed only when the asset is configured differently — e.g. a PV-only asset doesn't have a BESS-cycling loss row).

#	Row	Sign	Source class typically
1	P50 expected (weather-normalized) [L.1]	+	Calculated
2	Soiling losses [L.2]	–	Calculated
3	Inverter clipping [L.3]	–	Calculated
4	Curtailment (DG-side or grid-side) [L.4]	–	Judged (counterparty allocation)
5	Equipment downtime [L.5]	–	Measured
6	Tracker drift / mechanical issues [L.6]	–	Calculated
7	Weather variance vs P50 reference [L.7]	± (signed)	Calculated
8	Anomaly / unattributed [L.8]	–	Judged (review)
9	Actual energy delivered	=	Measured

2. Source classification — the four classes

Every figure in a LumeTrax deliverable is classified by source. The classification is the methodology property that makes the deliverable defensible to a lender's IE, an insurer, or a contract counterparty. Disagreements between counterparties typically resolve at the assumption-or-judgement layer.

Class	Definition	Property	Where it appears in the waterfall
MEASURED	Direct historian / metering / alarm-event record.	Repeatable, identifiable, verifiable, auditable, and defensible.	ES, AT, the source of the
CALCULATED	Derived from measured data via documented formulae.	Repeatable, identifiable, verifiable, auditable, and defensible.	ES, AT, the source of the
ASSUMED	Required input where measurement isn't available.	Documented, source-specific, and defensible.	ES, AT, the source of the
JUDGED	Reviewer interpretation where data is contested.	Defensible, the judgement is the reviewer's.	ES, AT, the source of the

Disagreements between counterparties typically resolve at the assumption-or-judgement layer. A measured value is reproducible; what's worth arguing about is the methodology, the assumption, or the judgement. Naming each figure's class makes that argument productive.

3. P50 expected (weather-normalized) — [L.1]

P50 expected energy is the foundation of the waterfall. Every loss bucket is measured against this baseline.

Definition

P50 expected energy is the energy a plant would produce under the irradiance, ambient temperature, and operational conditions actually observed during the period, assuming the plant operates at its as-built physical configuration with no equipment degradation, no soiling, no curtailment, and no downtime.

Formula

$$E_{P50} = \sum_t [POA_t \times A_{array} \times \eta_{module}(T_{amb_t}) \times \eta_{BOS} \times \eta_{inv}(P_{DC_t}) \times \Delta t]$$

Inputs

Symbol	Description	Source class
POA_t	Plane-of-array irradiance at time t, from on-site pyranometer array (15-min resolution, measured median).	Measured
A_array	Total module area (m ²) from as-built register.	Measured (commissioning)
$\eta_{module}(T_{amb_t})$	Module efficiency at observed ambient temperature, using OEM-published temperature coefficient.	Assumed - uses Assumed coefficient
η_{BOS}	Balance-of-system efficiency (cabling, transformer, etc.) — as-built or commissioning-test value.	Assumed (commissioning)
$\eta_{inv}(P_{DC_t})$	Inverter efficiency curve at observed DC power, OEM-published curve.	Calculated - uses Assumed curve
Δt	Period duration (hours) per time-step.	Measured (calendar)

Source class

P50 expected is CALCULATED. The formula is published. Inputs include some Measured values (POA, A_array, calendar) and some Assumed values (temperature coefficient, BOS efficiency, inverter curve). When a counterpart disputes the P50 number, the dispute resolves at one of the Assumed inputs.

4. Soiling losses — [L.2]

Definition

Energy lost due to dust, dirt, bird droppings, snow, or other particulate accumulation on PV module surfaces between cleaning cycles. Recoverable through cleaning.

Method

Cleaning-cycle inflection analysis. Soiling rate (% / week) is measured directly from the inflection in plant-level performance after each documented cleaning event. **Not** from a design assumption or OEM-published soiling rate.

Formula (per cleaning cycle)

```
soiling_rate = ( PR_pre_cleaning - PR_immediately_post_cleaning ) /  
weeks_since_last_cleaning
```

```
L.2_period = Σ_(t in period) [ E_P50_t × soiling_rate ×  
weeks_since_last_cleaning_t ]
```

Why this method (instead of OEM design rate)

OEM design assumptions (typically 1.0–1.2% / week) are useful for project bankability ahead of commissioning. After commissioning, observed soiling rates diverge — often materially — based on local site conditions (proximity to dust sources, vegetation, traffic, seasonal effects). The cleaning-cycle inflection method is observation-based and reflects the actual asset, not the design assumption.

ROI breakeven

When the observed soiling rate exceeds the cleaning ROI breakeven (typically 1.4% / week for utility-scale PV with current cleaning costs), Vision flags the row as **recoverable — washing recommended**. Below breakeven, the row is recorded but no operational action is triggered.

Source class

L.2 is CALCULATED. Inputs are Measured (PR pre/post cleaning, weeks elapsed). The cleaning-cycle inflection method is documented in IEC 61724-1 §6.3.

5. Equipment-side losses — [L.3] [L.5] [L.6]

5.1 Inverter clipping — [L.3]

Energy lost when DC array output exceeds the inverter's AC nameplate rating during peak irradiance hours.

Permanent (design intent) — recoverable only through repowering with higher-capacity inverters.

$$L.3 = \sum_t \max(0, P_{DC_t} \times \eta_{inv} - P_{AC_nameplate}) \times \Delta t$$

Source class: CALCULATED. All inputs Measured.

5.2 Equipment downtime — [L.5]

Energy lost when an inverter, BESS, switchgear, or other plant component is in fault, offline, or otherwise non-operational during a period when expected production was non-zero. Downtime is itself MEASURED (alarm-event records); the energy loss is CALCULATED (downtime hours × expected power during those hours).

$$L.5 = \sum_{(t \in \text{downtime_hours})} [E_{P50_t} \times (\text{capacity_offline} / \text{capacity_total})]$$

Source class: MEASURED for the downtime; CALCULATED for the energy loss. Counterparty allocation (PPA-recoverable / OEM warranty / O&M-attributable; / weather / grid) is per-event, applied during the counterparty allocation pass — see §7.

5.3 Tracker drift / mechanical issues — [L.6]

Energy lost when a single-axis or dual-axis tracker drifts from optimal pointing angle due to mechanical fault, sensor drift, or alignment issue. Detected via cohort analysis across tracker rows; rows operating below the cohort median by $\geq 0.5^\circ$ trigger a Vision flag.

$$L.6 = \sum_{(t, \text{row})} [E_{P50_row,t} \times (1 - \cos^2(\text{drift_angle_row}))]$$

Source class: CALCULATED. Drift angle is Measured (tracker telemetry). Recoverable through O&M; action (re-alignment, sensor calibration, mechanical repair).

6. Contract-side and unexplained losses — [L.4] [L.7] [L.8]

6.1 Curtailment — [L.4]

Energy that the plant could have produced but was prevented from delivering by a grid-side or DG-side instruction (PPA force-majeure clause, grid-operator curtailment command, DG-side hybrid dispatch logic, contracted output cap). The energy itself is **Calculated**; the counterparty allocation is **Judged**.

$$L.4 = \sum_{(t \in \text{curtailment_hours})} [E_{P50_t} \times \text{curtailment_ratio_t}]$$

Curtailment events are MEASURED (grid-operator records, hybrid dispatch logs, plant-controller setpoint records). The classification (**PPA force-majeure / grid-operator-driven / hybrid-dispatch / contractual cap**) requires reviewer judgement against the contract clauses — hence JUDGED for counterparty allocation.

6.2 Weather variance vs P50 reference — [L.7]

Difference between expected energy under **actual** observed weather and expected energy under **P50 reference** weather (long-term resource-assessment expectation). Can be positive or negative — a sunnier-than-expected period generates extra energy; a cloudier-than-expected period generates less.

$$L.7 = E_{P50_observed_weather} - E_{P50_reference_weather}$$

Source class: CALCULATED. Weather variance is permanent (the period has happened) and not recoverable through any operational action. Recorded for completeness; excluded from recovery expectations.

6.3 Anomaly / unattributed — [L.8]

Residual loss after all named buckets have been computed. The anomaly bucket exists because the named buckets together typically explain 95–98% of the gap, not 100%. Residuals come from minor measurement noise, sub-threshold equipment drift below the FDD trigger, or transient grid quality issues that don't appear as discrete events.

$$L.8 = E_{P50} - \text{Actual} - (L.2 + L.3 + L.4 + L.5 + L.6 + L.7)$$

Source class: JUDGED. When L.8 exceeds 1% of expected energy, the reviewer documents the residual and flags the asset for deeper FDD investigation in the next period. Material residuals (>2% of expected) are escalated to an Audit & Assurance engagement.

7. Counterparty allocation rules

Loss attribution decomposes **by cause**. Counterparty allocation maps each cause **to a contractual counterparty** for recovery purposes. Allocation is per-event, against the operating contract (PPA, EPC contract, O&M; contract, OEM warranty, insurance policy).

Cause (loss bucket)	Default counterparty allocation	Documentation required
L.2 Soiling	Operator-side recoverable	Soiling rate measurement · cleaning ROI evidence
L.3 Inverter clipping	Permanent (design intent) — no counterparty	As-built inverter sizing register
L.4 Curtailment — PPA force-majeure	PPA-recoverable under FM clause	PPA §FM clause reference · grid-operator records · curtailment
L.4 Curtailment — grid-operator-driven (inverter clipping)	Grid operator (oftaker) — typically recoverable per PPA	Grid operator notification records · setpoint logs
L.4 Curtailment — hybrid dispatch (DG-side optimization)	Grid operator (oftaker) — non-recoverable (operational optimization)	Grid operator dispatch log · contracted DG-share cap reference
L.5 Downtime — OEM warranty event	OEM warranty (within warranty window)	Alarm chronology · OEM warranty terms · claim filing record
L.5 Downtime — O&M response delay	O&M contractor (SLA breach if applicable)	SLA timer record · response timestamp · contracted response
L.5 Downtime — operator action / planned	Operator-side (planned maintenance, etc.)	Maintenance plan · work-order record
L.6 Tracker drift	Operator-side recoverable (or OEM warranty if mechanical analysis identifies)	Technical analysis · inverter warranty · service record
L.7 Weather variance	Permanent (non-recoverable)	Resource-assessment P50 reference · period weather record
L.8 Anomaly / unattributed	Reviewer judgement — typically operator-side until investigation resolves	Investigation notes · escalation if material

8. Worked example — period waterfall

This worked example uses the same synthetic figures as the Vision sample report (Q4 2025 · PV Project SAMPLE-001 · 50 MWp · MENA). Each row shows the input, the formula, the result, and the source class.

Step	Inputs (synthetic)	Result (MWh)	Class
P50 expected — observed weather	$ROA, T_{amb}, A_{array}, \eta_{module}, \eta_{BOS}, \eta_{inv}$ per §3 formula	53,725	Calculated
L.2 Soiling losses	Soiling rate 2.1% / week (measured) × 1 week-equivalent exposure (period-mean)	-208	Calculated
L.3 Inverter clipping (Block 04 design)	$\min(\max(0, DC \text{ over AC rating}) \times \Delta t)$ — Block 04 only	-430	Calculated
L.4 Curtailment (DG-side, PPA for curtailment)	Curtailment hours × E_P50_t × ratio — PPA §11.7 FM clause	-752	Judged
L.5 Equipment downtime (Block 04 capacity)	Capacity offline (1.5%) × period hours × E_P50 ratio	-322	Measured (downtime) / Calculated (energy)
L.6 Tracker drift (Row B12, drift 0.6°)	$(1 - \cos^2 0.6^\circ) \times E_{P50_row} \times \text{period}$	-86	Calculated
L.7 Weather variance vs P50 reference	Observed-weather E_P50 – reference-weather E_P50	+157	Calculated
L.8 Anomaly / unattributed	Residual after all named buckets — within 1% threshold	-274	Judged
Sum of named loss buckets	L.2 + L.3 + L.4 + L.5 + L.6 + L.7 + L.8	-2,835	Calculated
Actual energy delivered	Revenue meter — historian (15-min)	52,438 (53,725 - 2,835 + rounding)	Measured
Reconciliation check (Σ vs gap) Expected – Actual = 1,287 MWh ≈ Σ buckets – +157 weather = 1,287		within 0.1%	Methodology check

The reconciliation check on the bottom row is a methodology validation, not a separate calculation. If it doesn't reconcile within ~0.1%, the methodology has a gap — investigate before publication.

9. Methodology versioning and reconciliation

Version pinning

Methodology version is **pinned at engagement initiation**. The version number appears on every report cover and in every methodology footnote. Period-over-period comparability is guaranteed only within the same version. When the methodology updates between periods, the change is disclosed in the methodology section of the next report, and the prior period's figures are available for re-computation under the new version on request.

Reconciliation cadence

LumeTrax-derived loss attribution figures are reconciled against OEM-reported figures (when available) on a quarterly basis. Material deltas (>0.5% of expected energy) are documented in the report's reconciliation section with explanation per row. Reconciliation failure is not a methodology failure — different counterparties using different definitions for the same KPI is the norm. What matters is that each delta is named and explained.

Version history

Version	Date	Change
v1	2026-05-08	Initial published methodology aligned to IEC 61724-1 + IEC 61400-26-1. Cleaning-cycle inflection method documented

Reference standards

Standard	Application in this methodology
IEC 61724-1	PV system performance monitoring — POA irradiance measurement, weather normalization, soiling-cycle inflection method
IEC 61400-26-1	Capacity-weighted availability calculation — used in [L.5] equipment downtime energy-loss formula
pvlib (or equivalent physics-aware library)	Reference implementation for E_P50 calculation under observed weather
IEC 62443-4-1	Internal SDLC alignment for the calculation engine itself (versioning, change management, audit trail)

End of methodology.

© 2026 LumeTrax · Loss Attribution Methodology · Document version: loss-attribution-methodology-v1 · Issued 2026-05-08 · Resolves footnote references [L.1] through [L.8] in the Vision quarterly performance report sample and the Audit & Assurance bankability review sample. Updates published as the methodology evolves; version pinning per engagement.